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Panoramic Night Vision Goggle Testing for Diagnosis and Repair

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ABSTRACT

During operational testing of the panoramic night vision goggles (PNVG) over the past eighteen months, the prototype systems have shown wear which has resulted in degraded performance. When a PNVG degrades to a point that pilots find objectionable, the PNVGs are sent back to the lab for repair. The lab has set up a program to assess the PNVGs received from the field to verify the probable source of the objectionable characteristic(s). Once determined, the PNVGs are shipped back to the manufacturer for repair. After repair, the PNVGs are again shipped to the lab to verify repairs and assess the overall condition before returning the PNVG to the field for further operational testing. This paper discusses the selected series of tests that are performed to diagnose the more common recurring problems and to determine if the manufacturer satisfactorily repaired them. These tests include the assessment of: gain, maximum luminance output, visual acuity ("resolution"), objective lens focus range, eyepiece diopter setting, and image discontinuity at the inboard/outboard channel boundary. The results of this testing are presented along with a comparison of data taken before and after repair with data taken during previous evaluations.

INTRODUCTION

Under a Phase II Small Business Innovative Research (SBIR) program, a total of 10 PNVGs were delivered to the Air Force Research Laboratory for testing and for eventual operational utility evaluations (OUEs) conducted by pilots in the field. Although these PNVGs were designed for flight evaluation, they were not built to the level of ruggedness that might be achieved in a final, fielded design. As a result, the PNVGs required repair during flight testing. Since the PNVGs were not designed for any level of field maintenance, the only way to repair the PNVGs is to send them back to the manufacturer. However, because of the sometimes ambiguous deficiencies noted by the pilots, and the relatively high cost of PNVGs repaired, it was decided that a controlled procedure should be established to: 1) verify and document the nature of the pilots complaints through measurements of the PNVGs and 2) verify the condition of the PNVGs after repair and prior to returning them to the field. This paper describes the tests that were selected and some of the results obtained from PNVGs sent back for repairs.

PROCEDURES

Gain/Maximum Output Luminance

The gain of a night vision goggle (NVG) is an assessment of its ability to amplify available light. The maximum output luminance of an NVG is determined by providing a uniform input luminance (that fills the field of view) and increasing the input luminance until the output luminance no longer increases. This is the point at which the auto gain feature of the NVGs starts to control the system gain. These are measured using a Hoffman ANV-120. This device implements a test outlined in earlier documents [Task, 1993] in which the luminance output of the NVG is measured and compared to the luminance input from a spatially large, Lambertian, 2856K blackbody source. Gain is calculated simply by dividing the luminance output by the luminance input.

Visual Acuity

Visual Acuity [Marasco & Task, 1999] measures how well a human observer can see high contrast targets at specified light levels through the PNVG. The targets are a series of high contrast, square-wave gratings in steps of one Snellen acuity point (e.g. 20/24, 20/25, etc), illuminated to 5.8×10^{-3} foot-Lamberts (fL) (quarter moon) and to 5.8×10^{-4} fL (starlight) with a light source having a blackbody color temperature of 2856K. The test PNVG is placed 30 feet from the targets. Trained observers focus the NVGs on the target gratings and view the gratings through each ocular of the PNVG, one at a time using their dominant eye. The targets with the highest horizontal and vertical spatial frequencies the observer can clearly see, in terms of Snellen acuity, are then recorded. The trained observers (typically 3 are used

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and their results averaged) are required to be highly practiced with the test procedure and must have 20/20 vision or vision corrected to 20/20 and no astigmatism.

Objective Lens Focus Adjustment Range

The objective lenses of the inboard channels of the PNVGs are adjustable, permitting the observer to focus on objects located about 2 feet away to infinity. However, in order to give the PNVG user confidence that the objective lens focus is indeed set for best image quality at the infinity end, it is desirable to have the objective lens go "past" infinity. This enables the observer to adjust back and forth across the infinity setting to obtain the best possible focus. If the objective lens focus mechanism is not adjusted correctly, it may stop the lens travel short so that it does not go through infinity. This test is designed to insure the objective lens can be focused at and through the infinity setting. An IR LED, which serves as a point source of light, is located about 190 feet (anything past about 150 feet can be considered optical infinity for the PNVG objective lens) from the PNVGs. The objective lens focusing knob is then adjusted until the image of the LED is as small as possible such that this setting is not at the end of travel. Ideally, one would like the image to get smaller as the objective lens is focused at a distant object, then get larger as the adjustment is pushed past the minimum size image. This insures the PNVGs can be focused "past" infinity.

Eyepiece Focus

The current PNVG design has a fixed focus eyepiece. This means the virtual image of the image intensifier tube output screen is located at a fixed distance from the observer's eye. For various reasons beyond the scope of this paper, the original specification for the PNVG called for the eyepiece focus to be set to –0.75 diopters. To verify this focus setting, a hand-held dioptometer is used (Task, 2000). For this procedure, a single observer measured the diopter setting three times and the average was recorded as the diopter value.

Image Discontinuity

Extending a night vision device's horizontal field of view by combining the output of multiple image intensifier tubes creates the possibility of image discontinuities between the in-board and out-board channels due to the difficulties in aligning the optical systems. These discontinuities may be manifested as excessive overlap, gaps, magnification differences, image rotation differences, or image shifts. This procedure is designed to photographically assess and measure these defects by imaging a large 8 ft by 8 ft grid through the PNVG in-board and out-board channels simultaneously and comparing the defects to the size of grid features (Marasco & Task, 1999).

The PNVGs are mounted and positioned a known distance from the back-illuminated grid board (grid lines are spaced 8 inches apart). With the room lights off and the grid board lighting set to a very low level, both the in-board and out-board PNVG ocular fields of view are simultaneously photographed using a camera with a wide angle lens. Using the distance to the grid board and the grid board line spacing, it is possible to calculate the angular subtense of each of the 8-inch grid squares. Using this information to scale the photograph, it is possible to quantitatively assess image discontinuity.

Spectral Measurements

During operational testing of the PNVG, Army pilots noticed some color smearing in a PNVG II image. It was the observation of researchers at USAARL, Ft. Rucker, AL, that the problem could be corrected by attaching yellow absorption filters. However, Air Force fliers did not report this image anomaly. The question went largely uninvestigated until after the review of several PNVG image discontinuity photos. In these photos, a faint blue double image was found at the edges of the PNVG II output. Analysis of photos showed that the double image was not found in the PNVG I.

This issue is due in part to the spectral characteristics of the image intensifier tube's P43 phosphor. The P43 phosphor is attractive for use in the PNVG because the phosphor's primary emission spike is spectrally narrow. In order to take advantage of the narrow central spike, the two dim, secondary emissions (known as side lobes) must be attenuated. The PNVGs are equipped with an interference filter to block the side lobes and pass only the primary P43 phosphor spike.

Spectral measurements were used to examine the relative intensity of the blue image. The PNVG was prepared for these measurements by mounting it on an optical table and focusing them to infinity. A single PNVG objective lens was then aligned to the aperture of an integrating sphere so that the entire field of view is filled. The integrating sphere was illuminated with a 2856K source producing a luminance of approximately $0.7X10^{-3}$ fL. The spectroradiometer measurement head, having a 4.1-degree field of view, is positioned several inches behind the test NVG on the test

channel's optical axis and focused into the eyepiece. NVG output is then measured for two different view angles: on axis and 15 degrees off axis.

EXAMPLES OF RESULTS

The following is an example of the kind of data obtained from the field that accompanies a PNVG that has been returned for repair or refurbishment. Only the comment in parentheses was added for emphasis in this paper:

> **PNVG II, Config. 4, S/N 02 - 5 JUN 0**
> Got opportunity to check out:
> - Left inner channel is dim. Appears to be "gained down."
> - Very difficult to focus.
>
> Left outer - 20/60
> Left inner - 20/50 very dark
> Right inner - 20/40
> Right outer - 20/60
> Headache after wearing for 20 min
> * compared with Oct 27, 99 entry (7 months prior to this entry). The goggles have experienced a large reduction in performance
>
> **PNVG I, Config. 1, S/N 08 - 8 JUN 00**
> - Return to Sytronics for MX.
> - Visual acuity is poor - focus at infinity needs work
> - Loose VA. Please tighten
> - Scratch in Rt outer channel

As illustrated above, the nature of the complaint was not always exactly clear. For the first case (the PNVG II), there were two characteristics to check: 1) the left inboard channel appeared to have lower gain than it used to compared to the other channels, and 2) the visual acuity may have been reduced. It was hard to determine what the cause might be (as evidenced by the comment that the "goggles have experienced a large reduction in performance" since the previous entry of Oct 27, 99). The reference to focus difficulty could be due to mechanical friction (i.e. it is physically hard to turn the knobs) or could be a reference to the image quality obtained (i.e. it does not focus as clearly as it used to). Gain and visual acuity assessments were considered the two key parameters to concentrate on in the evaluation. The comment about headache after wearing for 20 minutes could be caused by any number of things. One possible culprit could be image alignment problems, making it another parameter to investigate closely.

The second case (PNVG I) provided a hint that the focus range of one of the oculars may not be focusable to or past infinity. The reference to VA was presumably "visual acuity" although it was difficult to determine how to "tighten" the visual acuity. The following are the log entries for these PNVGs when they came back from the repair:

> **PNVG II, Config. 4, S/N 02 13 JUN 00**
> Received goggle from Sytronics. Initial observations:
> All four tubes exhibit dark shaded areas. These are caused by "poison" in the cathode and will most likely kill entire tube within few months. I notified Sytronics before any repairs.
> Left outer, right inner and right outer tubes re-adjusted for gain and Automatic Brightness Control (ABC). Focus on all four objectives re-adjusted. Inner channels read 20-22.
>
> **PNVG I, Config. I, S/N 08 21 JUN 00**
> Goggle received from Sytronics.
> a. Initial check showed left side dead.
> b. Right side misaligned and soft image.
> c. Stow mechanism (trapeze) loose.
> d. Left inner tube has dark shading (poison of photocathode)
> e. Left outer tube has dark shading [diagram]
>
> All items (except tube shadings) were corrected between June 30 and July 5, 2000.
> 1. Left power supply re-wired.
> 2. Right monocular re-adjusted, but central intensifier is soft (see 27 March comments).
> 3. Stow mechanism re-tightened.

4. Goggle shipped July 6, 2000 to Sytronics.

The following sections show the test results for these two PNVGs with their reported problems before and after repair.

Gain

Since there is a certain amount of variability in repeatability and reproducibility of gain measurements, only changes in gain of greater than 13% are considered significant [Aleva, 1998]. Although the repair contractor stated that gain and ABC (i.e. maximum luminance) was adjusted for 3 of the 4 channels of the PNVG II (all but the left inner channel) it is apparent from Table 1 that only the right channels had a significant increase in gain as a result of the repair. It should also be noted that even before repair the left inner channel, which was stated to be "dim," had the highest gain of all 4 channels (PNVG II) and the second highest maximum luminance. This makes it unclear as to what conditions caused the pilots to note the luminance deficiency in the left inner channel. Table 2 summarizes the results of the maximum luminance output measurements, showing an increase in maximum output luminance for the left outboard and right inboard channels of the PNVG II after repair. The PNVG I data for both Tables 1 and 2 indicate essentially no change before and after repair, which makes sense since the pilot complaints did not involve any gain or luminance related issues.

Table 1. Gain measured at $3.7\text{x}10^{-4}$ fL input before and after repair.

	PNVG I		**PNVG II**	
	Before	**After**	**Before**	**After**
LFT OUTB.	3568	3919	3132	2993
LEFT	4422	4405	3655	3567
RIGHT	4878	5027	3602	4954
RT OUTB.	4846	5189	2981	4181

Table 2. Maximum output luminance (fL) measured on three different dates.

	PNVG I		**PNVG II**	
	Before	**After**	**Before**	**After**
LFT OUTB.	2.74	2.72	2.19	3.06
LEFT	2.74	2.89	2.41	2.41
RIGHT	2.41	2.49	1.84	2.33
RT OUTB.	2.48	2.70	2.52	2.47

Visual Acuity (Resolution)

Table 3 and Table 4 list the results of acuity testing at starlight and quarter moon luminance conditions respectively. These tables show minor improvements in visual acuity (smaller numbers) for most of the channels after repair, which is expected based on the pilot complaints and the stated repairs. However, previous research on the techniques to measure visual acuity indicates that the magnitude of these changes is probably insignificant compared to the repeatability/reproducibility of the measurements [Pinkus et al., 1999].

Table 3. Starlight Snellen Acuity (20/XX) measured before and after repair.

	PNVG I		**PNVG II**	
	Before	**After**	**Before**	**After**
LFT OUTB.	44	42	40	38
LEFT	32	37	29	29
BINOCULAR	35	35	27	28
RIGHT	43	41	29	28
RT OUTB.	43	41	43	40

Table 4. Quarter Moon Snellen Acuity (20/XX) measured before and after repair.

	PNVG I		PNVG II	
	Before	**After**	**Before**	**After**
LFT OUTB.	39	39	34	32
LEFT	29	30	25	26
BINOCULAR	28	32	25	25
RIGHT	39	35	25	26
RT OUTB.	38	38	39	34

Objective Lens Focus Adjustment

Focus issues noted in PNVG II, Configuration 4, serial number 02 were corrected by insuring the objective lens focus range went past infinity.

Eyepiece Diopter Setting

None of the pilot complaints seemed to be a result of eyepiece focus setting. Although the diopter settings of Table 5 are somewhat varied, they do not indicate that there should be any difficulties due to this parameter.

Table 5. Mean Eyepiece Setting (in Diopters) measured on three different dates.

	PNVG I		PNVG II	
	Before	**After**	**Before**	**After**
LFT OUTB.	-0.8	-0.6	-0.7	-0.6
LEFT	-0.6	-0.5	-0.4	-0.5
RIGHT	-0.5	-0.5	-0.3	-0.5
RT OUTB.	-0.4	-0.2	-0.2	-0.3

Image Discontinuity

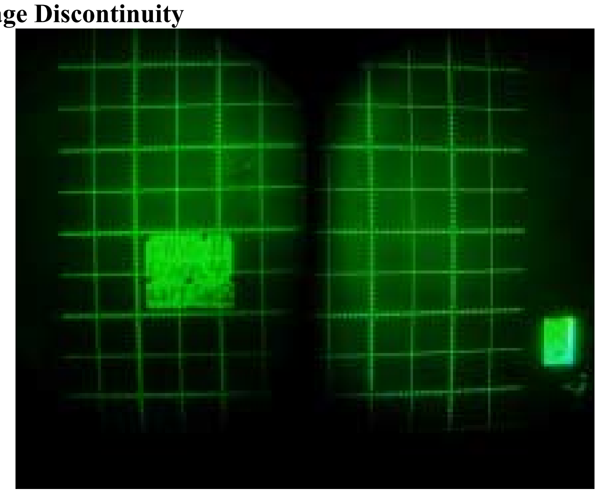

Figure 1. PNVG II image discontinuity before repair.

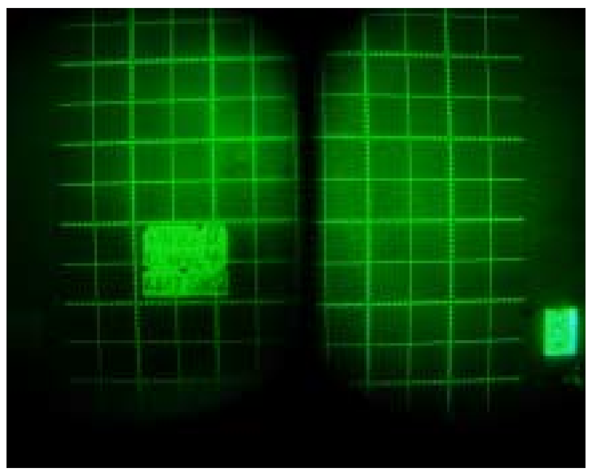

Figure 2. PNVG II image discontinuity after repair.

Since the manufacturer's procedure for adjusting image intensifier tube gain was unknown, changing the relative position of the tube to the eyepiece, thus changing PNVG image discontinuity, was considered possible during repair. Image discontinuity photos taken before and after repairs were compared (Figure 1 and Figure 2). Little change was noted in photos of either PNVG I or PNVG II.

Spectral Measurements

Figure 3 shows the spectral distribution for PNVG II, Configuration 4, serial number 0003, on axis and 15 degrees off axis. The spectral measurements indicate that the current filter is sufficient to block the blue and red side lobes on axis. However, at 15 degrees off-axis the blue side lobe appears. The intensity of the blue lobe ranged from 2% to 17% of the corresponding green primary emission depending on the ocular.

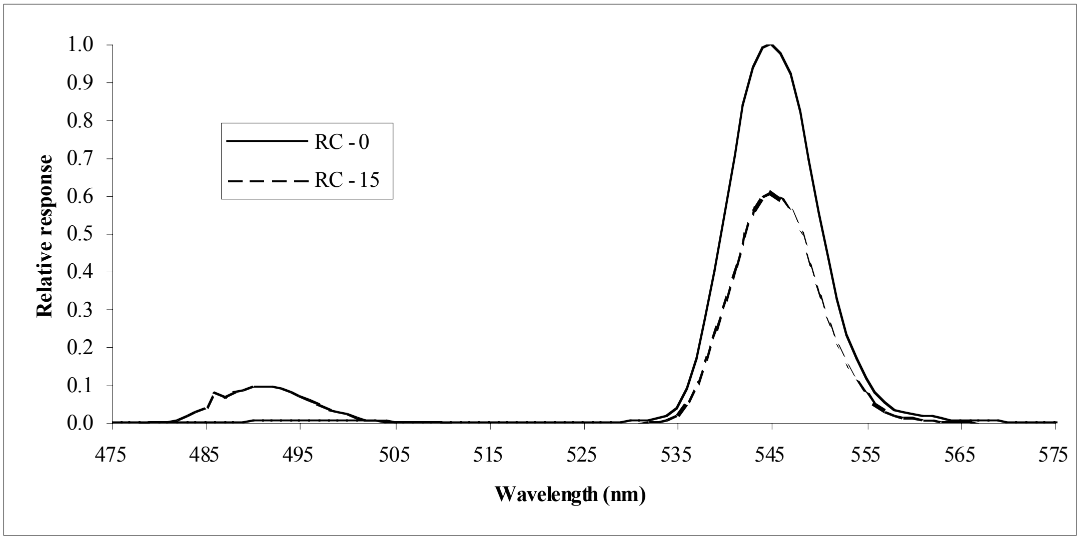

Figure 3. Normalized spectral measurements of PNVG II, Config. 4, S/N 0003, Right Central Channel, at 0 and 15 degrees off axis.

DISCUSSION AND CONCLUSIONS

The characterization of PNVGs for diagnosis of image quality problems and post repair assessment yielded a number of observations. Given the sometimes ambiguous comments from the pilots regarding the deficiencies of the PNVGs due to wear and tear in the field, it is apparent that a controlled process of quantitatively verifying PNVG performance before and after repair is needed. One curious item of note is the large difference in visual acuity ascribed to the PNVGs from the field compared to the more controlled assessment of PNVG visual acuity accomplished in the laboratory. The repeatability and reproducibility of NVG visual acuity is a good topic for future research.

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